# BASIS FOR COST ESTIMATE OF A PUSH-PULL LIXIVIANT PILOT TEST AT AREA N, HANFORD SITE

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**Principles of a Push-Pull Lixiviant Pilot Test**

The concept of a push-pull test is to inject (push) into an aquifer a given volume of water containing known concentration of a conservative solute (tracer). The subsequent extraction (pull) will then remove this water from the aquifer. The time needed to extract a full load of the injected solute is longer than the injection time because of dispersive properties of the aquifer. Thus a diagram of the conservative solute concentration versus time combined with appropriate formulas allow for determination of the aquifer's dispersivity.

If the injected water contains also a reactive solute, then, knowing dispersivity, conclusions can be reached regarding its reactivity with the contaminant present in the aquifer either in solid or dissolved phase. In case of the potassium chloride (KCl) lixiviant that will be used at Area N, chloride (Cl) is a conservative solute (tracer) and potassium (K) is a reactive solute whose effectiveness for removing strontium-90 (Sr90) from the aquifer needs to be tested.

It is expected that nearly 100% of the mass of the injected conservative tracer will be removed during extraction. The extraction period will be longer than the injection period if conducted at the same rate of flow. However, only a fraction of the reactive solute mass will be removed, the rest being left in the aquifer adsorbed to its solid matrix. With the exception of the initial portion of the extraction period, the concentration of the reactive solute (K) in the pumped water will always be lower than that in the injected water.

Concentration of the conservative tracer (Cl) in the extracted effluent will also be highest during the initial portion of the extraction period, but being affected only by the dispersivity of the aquifer, its concentration will remain relatively stable over the first part of the extraction period and then gradually decline.

It is anticipated that, because Sr90 (and much greater quantities of calcium, magnesium, cold strontium, and other exchangeable cations) present on the solid matrix will be replaced by potassium, the beginning of the Sr90 concentration curve will be a mirror image of the one for potassium. In other words, the initial Sr90 concentration will be very low, and will gradually increase to a certain level marking its maximum desorption in the presence of a certain concentration of potassium.

From those initial levels, concentrations of Sr90 and potassium will decline as more native water, which was pushed away from the well during its injection stage, is mixed into the extraction stream. The Sr90 concentration will eventually return to the pre-injection (background) level. However, the Sr90 concentration should drop to a level lower than background for some period late in the extraction phase of the test. This phenomenon is expected because native contaminated groundwater flowing to the extraction well will lose some Sr90 (and other exchangeable cations) as it displaces adsorbed potassium on the sediments. Consequently, the concentration of potassium should remain slightly elevated for some period before eventually returning to its background level.

The lixiviant push/pull test could be successfully conducted as a stand-alone experiment. However, to provide an additional level of confidence that the injected lixiviant can be adequately removed from the aquifer using a given well infrastructure, an additional tracer test preceding the lixiviant pilot test is proposed. The preliminary tracer test will be conducted using a very conservative tracer, bromide (Br) introduced to the aquifer as a solution of sodium bromide (NaBr). The tracer will be added to contaminated water previously extracted from the aquifer. If the results of the bromide test are deemed appropriate, the aquifer will be left unstressed for a short time to recover its original flow conditions and Sr90 concentration, and the lixiviant pilot test will then be performed.

**Infrastructure**

The pilot test will require:

- One water well screened over most of the saturated thickness of the aquifer (approximately 10 meters), similarly to injection/extraction wells that would be used in the proposed soil flushing system,
- Water storage, containment, transportation, and treatment facilities sufficient to handle water pumped from the well during extraction.
- An uncontaminated (no Sr90) water supply located in the area with other geochemical characteristics similar to the injection/extraction well in question.

**Procedure**

<u>General</u>

The bromide tracer test will consists of the following Steps:

1. Extraction of Sr90-contaminated groundwater to:
    - establish optimal extraction rate from the given well to be used later for the tracer test and lixiviant pilot test,
    - measure the long term average level of contamination,
    - store water of the same quality and contamination level as present in the aquifer to be used for:
        - establishing steady-state flow-conditions (Step 3) prior to the tracer test,
        - injection of the tracer (Step 4), and
        - establishing steady-state flow-conditions prior to the lixiviant pilot test (Step 7).
2. Recovery period to reestablish natural groundwater-flow conditions.
3. Injection of a portion of the stored groundwater to establish steady-state flow conditions for the tracer test that will be conducted at the selected injection rate.
4. Injection of another portion of stored groundwater laden with sodium bromide as a tracer.
5. Extraction of sodium-bromide-laden water that was injected at Step 4, and directing it to storage or a treatment facility. It is expected that this water will have lower concentration of sodium bromide than injected water but the same concentration of Sr90 than the original groundwater. It is anticipated that this water will be discharged to a water treatment facility.

The push-pull lixiviant pilot test will consists of the following Steps:

6. Recovery period to allow aquifer returning to its original flow conditions and to analyze the results of the tracer test. If the analysis is satisfactory to regulators the push-pull lixiviant test will follow.
7. Reinjection of the last portion of water stored at Step 1, to establish steady-state flow conditions for the selected injection rate.
8. Injection of clean groundwater laden with lixiviant. This clean groundwater will be received from another water well located in an Sr90-clean zone.
9. Extraction of the loaded lixiviant and directing it to a storage or treatment facility. It is expected that this water will have much higher concentration of Sr90 than the original groundwater and lower concentration of lixiviant. The total mass of chloride, however, recovered from the well should nearly equal the total mass of chloride injected at Step 8.

<u>Injection/extraction rates and times</u>

It is foreseen that:

- At the start of Step 1 the extraction rate will be 15 gpm or 82 $m^3$/d. It will then be adjusted, if needed, to find the optimal discharge/injection rate. This optimal rate will be used for extraction during Steps 5 & 9, and injection during Steps 3, 4, 7 & 8.
- Extraction period (Step 1) will last 3.5 days and, assuming that the optimal rate is 15 gpm, the ***total of 287 $m^3$ or 75, 600 gallons of contaminated water to be temporarily stored***.
- Recovery period (Step 2) will last two days.
- Injection (Step 3) will last one day (total of 82 $m^3$).
- Injection of stored groundwater laden with sodium bromide (Step 4) will last 1.5 days (total of 123 $m^3$).
- Extraction of sodium-bromide laden water (Step 5) will last three times longer than the injection period of Step 4, i.e. 4.5 days (***total of 369 $m^3$ or 97,000 gallons of contaminated water to treat***). This estimate of the extraction time is not in discrepancy with the curves presented in Figures 1 & 2, because the dispersive properties of the aquifer will also affect the solute transport during the reversed flow, i.e. extraction.
- Recovery period (Step 6) will last a minimum of two days. The results of the bromide tracer test will be presented to the site and state regulators during this period and it is anticipated that approval for the lixiviant test will require substantially more than two days.
- Reinjection of the water stored at Step 1 to the aquifer, to establish steady-state flow (Step 7) will last one day (total of 82 $m^3$).
- Injection of clean groundwater laden with lixiviant (Step 8) will last one and one-half days (total of 123 $m^3$).
- Extraction of loaded lixiviant (Step 9) will last five times longer than the injection period of Step 8, i.e. seven and one-half days (***total of 615 $m^3$ or 162,000 gallons of water to be stored or treated***). This period is longer than that for the analogous action of Step 5 to provide for longer observation of Sr90 concentration in the extracted water.

<u>Alternate Procedure</u>

To minimize storage capacity necessary to contain contaminated water extracted at Step 1, it may be possible to limit this extraction to the amount needed for reinjection at Steps 3 and 4 only, i.e. to ***205 $m^3$ or 54,000 gallons***. The remaining 82 $m^3$ will then be extracted during one day of pumping following Step 6. Referring to this additional action, Step 6a, it will be followed by an additional one-day recovery period (Step 6b) that will precede Step 7.

**Comments on Performance**

1. Assuming the aquifer thickness of 10 m, effective porosity 0.24, and no dispersivity (piston-like flow), a cylindrical-shape zone of the aquifer affected by the non-reactive solutes (bromide and chloride) will have a radius of approximately four meters at the end of Steps 4 and 8.
2. Dispersivity of 0.05 m will spread this front so that 10% of the initial concentration would have been detected at 4.60 meters, but
3. Dispersivity of 0.20 m will spread this front so that 10% of the initial concentration would have been detected at 5.30 meters.
4. The size of a cylindrical-shape zone of the aquifer affected by the reactive part of the lixiviant (potassium) will likely by smaller since the portion of potassium will be "used" for replacing the exchangeable cations including Sr90.

**Solution Concentration**

Sodium bromide used for the tracer test will be injected at concentration of 400 mg/l of bromide, which corresponds to the concentration of 115 mg/l of sodium. Considering that injection of Step 4 will last for 1.5 days at the rate of 15 gpm (82 $m^3$/day) approximately 64 kg of sodium bromide will be used.

Potassium chloride used for lixiviant pilot test will be injected at concentration of 0.48 molar, i.e. 35,722 mg/l, corresponding to 18,725 mg/l of potassium. Considering that injection of Step 8 will last for 1.5 days at the rate of 15 gpm (82 $m^3$/day), approximately 4393 kg of potassium chloride will be used.

**Costs**

Equipment Costs

| Item | Unit Price | Unit | Quantity | Total Quantity | Total Cost | Footnote |
|---|---|---|---|---|---|---|
| KCl | $ 0.22 | 50 lb. bags | 200 | 10000 | $ 2,150.00 | *1* |
| NaBr | $ 1.69 | 200 lb. drum | 1 | 200 | $ 338.00 | *1* |
| Delivery of chemicals | $ 50.00 | one-way trip | 1 | 1 | $ 50.00 | *1* |
| 24gpm@120ft pump | $ 417.00 | pump | 1 | 1 | $ 417.00 | *2* |
| Primary tanks | $ 3,944.00 | tank | 15 | 15 | $ 59,160.00 | *3* |
| Secondary containment tanks | $ 4,235.00 | tank | 15 | 15 | $ 63,525.00 | *3* |
| Tank - 500 gallon | $ 473.00 | tank | 1 | 1 | $ 473.00 | *3* |
| Delivery & handling for tanks | $ 9,671.00 | load | 2 | 2 | $ 19,342.00 | *3* |
| 1,250 lbs./hr chemical feeder | $ 456.00 | feeder | 1 | 1 | $ 456.00 | *4* |
| Controller for feeder | $ 133.00 | controller | 1 | 1 | $ 133.00 | *4* |
| Tank mixer, 3/4HP, 60" long | $ 1,500.00 | mixer | 1 | 1 | $ 1,500.00 | *4* |
| Cord for mixer, 12/3, 20' | $ 0.85 | foot | 20 | 20 | $ 17.00 | *4* |
| Plug for mixer | $ 17.00 | plug | 1 | 1 | $ 17.00 | *4* |
| Receptacle for mixer | $ 19.00 | receptacle | 1 | 1 | $ 19.00 | *4* |
| Compaq Presario notebook PC | $ 1,180.00 | notebook | 1 | 1 | $ 1,180.00 | *5* |
| Orion pH/ion meter | $ 720.00 | meter | 1 | 1 | $ 720.00 | *6* |
| Ion-selective electrode - Br | $ 176.00 | electrode | 1 | 1 | $ 176.00 | *6* |
| Ion-selective electrode - Ca | $ 215.00 | electrode | 1 | 1 | $ 215.00 | *6* |
| Ion-selective electrode - Cl | $ 176.00 | electrode | 1 | 1 | $ 176.00 | *6* |
| Ion-selective electrode - K | $ 215.00 | electrode | 1 | 1 | $ 215.00 | *6* |
| Ion-selective electrode - Na | $ 121.00 | electrode | 1 | 1 | $ 121.00 | *6* |
| Ion-selective electrode - Hardness (Ca/Mg) | $ 215.00 | electrode | 1 | 1 | $ 215.00 | *6* |
| Ion-selective solutions - Br | $ 63.00 | solution | 1 | 1 | $ 63.00 | *6* |
| Ion-selective solutions - Ca | $ 63.00 | solution | 1 | 1 | $ 63.00 | *6* |
| Ion-selective solutions - Cl | $ 63.00 | solution | 1 | 1 | $ 63.00 | *6* |
| Ion-selective solutions - K | $ 63.00 | solution | 1 | 1 | $ 63.00 | *6* |
| Ion-selective solutions - Na | $ 63.00 | solution | 1 | 1 | $ 63.00 | *6* |
| Ion-selective solutions - Hardness (Ca/Mg) | $ 63.00 | solution | 1 | 1 | $ 63.00 | *6* |
| **EQUIPMENT COST** | | | | | **$ 150,993.00** | |
| **MISC PARTS AND CONNECTIONS @ 5%** | | | | | **$ 7,549.65** | |
| **TOTAL COST** | | | | | **$ 158,542.65** | |

***Footnotes:***

*1* Chemicals from Van Waters & Rogers. Reagent grade. KCl in 50 lb. bags & NaBr in 200 lb. drum. Delivery from Spokane to Hanford.

*2* Pump from NW Pipe. Portable/submersible 24gpm at 120' head. Includes pump, 3/4HP motor, pigtail.

*3* Tanks from American Tank Co. Constructed of polyethylene with primary placed inside secondary for containment.

*4* Chemical feeder, tank mixer, and accessories from McMaster-Carr.

*5* Notebook PC from Buy.com website. Used for data logging.

*6* Ion meter, electrodes, and solutions from Cole-Parmer. Meter will read concentrations in ppm, log 25 readings, and interface with PC.

Cost by Task with Equipment and Labor Included

**Task 1: Develop Final Design and Test Plan**

| | | | | | |
|---|---|---|---|---|---|
| Project Manager | 40 | hr. @ | $85.00 | $3,400 | |
| Staff Geohydrogeologist | 60 | hr. @ | $95.00 | 5,700 | |
| Senior Mechanical Engineer | 8 | hr. @ | $80.00 | 640 | |
| Quality Control Engineer | 24 | hr. @ | $65.00 | 1,560 | |
| Staff Support | 80 | hr. @ | $45.00 | 3,600 | |
| **Subtotal Task 1** | 212 | | | | $14,900 |

**Task 2: Review of Test Plan**

| | | | | | |
|---|---|---|---|---|---|
| Project Manager | 40 | hr. @ | $85.00 | $3,400 | |
| Staff Geohydrogeologist | 40 | hr. @ | $95.00 | 3,800 | |
| | 80 | | | | $7,200 |
| Travel to Hanford | | | | | 2,000 |
| **Subtotal Task 2** | | | | | $9,200 |

**Task 3: Mobilize and Install Equipment**

| | | | | | |
|---|---|---|---|---|---|
| Project Manager | 20 | hr. @ | $85.00 | $1,700 | |
| Geohydrologist | 60 | hr. @ | $55.00 | 3,300 | |
| Process Technician | 80 | hr. @ | $70.00 | 5,600 | |
| | 160 | | | | $10,600 |
| Equipment | | | | | 158,543 |
| Travel to Hanford | | | | | 7,200 |
| **Subtotal Task 3** | | | | | $176,343 |

**Task 4: Tracer Test**

| | | | | | |
|---|---|---|---|---|---|
| Project Manager | 10 | hr. @ | $85.00 | $850 | |
| Geologist | 80 | hr. @ | $80.00 | 6,400 | |
| Geohydrologist | 80 | hr. @ | $55.00 | 4,400 | |
| Process Technician | 240 | hr. @ | $70.00 | 16,800 | |
| **Subtotal Task 4** | 410 | | | | $28,450 |

**Task 5: Interpretation and Reporting of Tracer Test**

| | | | | | |
|---|---|---|---|---|---|
| Project Manager | 20 | hr. @ | $85.00 | $1,700 | |
| Staff Geohydrogeologist | 30 | hr. @ | $95.00 | 2,850 | |
| Geohydrologist | 40 | hr. @ | $55.00 | 2,200 | |
| Staff Support | 40 | hr. @ | $45.00 | 1,800 | |
| **Subtotal Task 5** | 130 | | | | $8,550 |

**Task 6: Lixiviant Pilot Test**

| | | | | | |
|---|---|---|---|---|---|
| Project Manager | 20 | hr. @ | $85.00 | $1,700 | |
| Geologist | 80 | hr. @ | $80.00 | 6,400 | |
| Geohydrologist | 80 | hr. @ | $55.00 | 4,400 | |
| Process Technician | 240 | hr. @ | $70.00 | 16,800 | |
| | 420 | | | | $29,300 |
| Travel to Hanford | | | | | 7,200 |
| **Subtotal Task 6** | | | | | $36,500 |

**Task 7: Interpretation and Reporting of Pilot Test**

| | | | | | |
|---|---|---|---|---|---|
| Project Manager | 80 | hr. @ | $85.00 | $6,800 | |
| Staff Geohydrogeologist | 80 | hr. @ | $95.00 | 7,600 | |
| Staff Geochemist | 80 | hr. @ | $95.00 | 7,600 | |
| Geohydrologist | 80 | hr. @ | $55.00 | 4,400 | |
| Staff Support | 120 | hr. @ | $45.00 | 5,400 | |
| **Subtotal Task 7** | 440 | | | | $31,800 |
| G & A (on non-labor) | | | | | 24,492 |
| Fee (on non-labor) | | | | | 19,944 |
| | | | **TOTAL ESTIMATED COSTS** | | **$350,179** |

* This Estimate valid for 90 days.

## Constraints and Assumptions

- The natural flow velocity of groundwater at the location of the injection/extraction well is low (preferable less than 0.15 m/day or 0.5 foot/day).
- The concentration of radioactive Sr90 in the water extracted during Steps 5 & 9 does not create health hazard for using single-ion electrodes for the real-time measurements of bromide, chloride, potassium, calcium, magnesium and sodium. The concentration of Sr90 during Step 9 may be as high as 200,000 pCi/l.
- Hanford would provide analysis of samples of effluent for Sr90, strontium, calcium, magnesium, potassium, chloride, bromide, sodium, and iron. Approximately 100 samples would be analyzed with an expected 72-hour turnaround for the non-radioactive concentration measurements.
- Chloride is a conservative tracer; i.e. its concentration in solution is not affected by the lixiviant cleanup activities.

- Sodium at low, 115 mg/l, concentration injected at Step 1 does not affect the reactivity of potassium with Sr90.
- Hanford would provide site-specific radiological worker training if required. MSE employees have radiological worker Level 2 training from Brookhaven National Lab that is current through 6/22/01.
- Site preparation and all utilities and utility connections supplied by Hanford.
- All equipment to be abandoned in-place with Hanford responsible for decontamination or disposal of the equipment.
- All waste handling will be performed by Hanford.